Enhanced PF Scheduling Algorithm for LTE Downlink System

Mohamad I. Elhadad[1], El-Sayed M. El-Rabaie[2], Mohammed Abd-Elnaby[3]

Department of Electronics and Electrical Communications, Faculty of Electronic Engineering, Menoufia University, Menouf, 32952, Egypt.

[1]mhmd_elhdad@yahoo.com; [2]srabie1@yahoo.com; [3]moh_naby@yahoo.com.

Abstract

A key feature of Long Term Evolution (LTE) system is the adoption of advanced Radio Resource Management (RRM) procedures in order to increase the system performance. Packet scheduling mechanisms play a fundamental role, because they are responsible for choosing how to distribute radio resources among different stations. In this paper, a modified Proportional Fair (PF) scheduling algorithm is proposed for capacity enhancement for LTE system and compared with the PF downlink scheduler, which is characterized by high fairness but with low spectral efficiency. Simulation results show that the proposed algorithm enhances the overall system capacity and also provides fairness in the distribution of the resources. The proposed algorithm improves the average cell throughput by more than 10.3%, with approximately the same fairness level (2.6% reduction) as compared with the conventional PF scheduling algorithm.

Keywords

LTE; Packet Scheduling; Fairness; RRM

Introduction

The LTE standardized by Third Generation Partnership Project (3GPP) [3GPP (2012)] has become the most important radio access technique for providing mobile broadband to the mass market. The introduction of LTE will bring significant enhancements compared to High Speed Packet Access (HSPA) in terms of spectrum efficiency, peak data rate and latency. Since the initial release in 2008, a slightly modified version (Release-9) and a complete fourth generation standard named LTE-Advanced (Release-10) have been developed [Chadchan & Akki (2010)]. LTE uses Orthogonal Frequency Division Multiple Access (OFDMA) in the downlink. OFDMA divides the frequency band into a group of mutually orthogonal subcarriers, thereby improving the system capabilities by providing high data rates, supporting multi-user diversity and creating resistance to frequency selective fading of radio channels [Ali & Zeeshan (2012), Talevski & Gavrilovska (2012), Larmo et al. (2009)].

Basic LTE network elements consist of a powerful evolved Node B (eNB) station and several User Equipments (UEs) in addition to a gateway. Basic packet scheduling is implemented by the network operator in UE and eNB station for both uplink as well as downlink. However, there are no rigid specifications set by 3GPP for scheduling mechanism leaving the details at the discretion of service provider. Packet scheduling comes under RRM and its main functionality is to decide users that would transmit their data on the air interface. The scheduling should integrate fairness in terms of throughput as well as the service policies to which users subscribe [Hara & Prasad (2003), Furht et al. (2009), Holma & Toskala (2009), Ergen (2009)].

The design of a downlink scheduling algorithm is a complex procedure and presents a number of design challenges, such as maximization of the system capacity and spectral efficiency, fairness approach, bit error performances and etc. [Tran & Eltawil (2012)]. Several algorithms have been proposed in literature to provide higher spectral efficiency with fairness ensured to all its users, the scheduling algorithm in [Schwarz et al. (2011)], for example, tries to make this balance using Assignment Model, which effectively maps UEs to RBs during each TTI. The proposed algorithm in [Schwarz et al. (2011)] makes modification on the best-Channel Quality Indicator (best-CQI) algorithm, which is characterized by high data rates at cell level but poor fairness, trying to provide fairness in the distribution of the resources, while at the same time keeping the system capacity utilization as high as possible.

In [Chadchan & Akki (2013)], the authors proposed a method for multi-user scheduling that operates on the boundary of the achievable multiuser rate region while guaranteeing a desired long term average fairness. Another scheduling algorithm based on the utility function has been implemented in [Kela et al.

(2008)], in order to improve the performance of the LTE system, particularly, improving the throughput and fairness performance. The throughput fairness between users can be effectively controlled by dividing the packet scheduler into a time domain and a frequency domain and utilizing different algorithms in both domains, as implemented in [Wengerter et al. (2005)].

A Generalized Proportional Fair (GPF) scheduling approach and its application to OFDMA with frequency scheduling has been presented in [Li et al. (2010)], and compared to a system without frequency scheduling, this increases the system throughput and yields an improved fairness with respect to the allocated resources and the achieved data-rate per user. An adaptive proportional fair scheduling algorithm for LTE system has been proposed in [Xie & Hui (2011)] which provides a good trade-off between capacity and fairness, by adjusting the scheduling priority according to individual user's channel condition.

A typical way to find a trade-off between requirements on fairness and spectral efficiency is the use of PF scheme [Kawser et al. (2012), Parruca et al. (2013), Girici et al. (2010), Sun et al. (2006)]. In this paper, we try to improve the performance of the LTE system by improving the throughput and fairness performance of the well known PF scheduling algorithm; then the performance of the proposed algorithm is compared to other algorithms in the literature; followed by evaluation on the performance of the proposed algorithm via simulations and the conclusion is made that the proposed algorithm is very efficient in terms of both throughput and fairness.

The rest of the paper is organized as follows: in Section 2 a basic background on the LTE technology is provided. Section 3 deals with the framework for LTE Downlink scheduling. We review and discuss the traditional PF algorithm, and then our modified PF scheduling algorithm is presented in section 4. Performance evaluation and simulation results are given in section 5 followed by the conclusion in section 6.

Overview of LTE System

LTE has been designed as a highly flexible radio access technology in order to support several system bandwidth configurations (from 1.4 MHz up to 20 MHz). Radio spectrum access is based on the Orthogonal Frequency Division Multiplexing (OFDM) scheme. In particular, Single Carrier Frequency Division Multiple Access (SC-FDMA) and OFDMA are used in uplink and downlink directions, respectively. Different from basic OFDM, they allow multiple accesses by assigning sets of sub-carriers to each individual user. OFDMA can exploit sub-carriers distributed inside the entire spectrum, whereas SC-FDMA can use only adjacent sub-carriers. OFDMA is able to provide high scalability, simple equalization, and high robustness against the time-frequency selective nature of radio channel fading. On the other hand, SC-FDMA is used in the LTE uplink to increase the power efficiency of UEs, given that they are battery supplied [Piro et al. (2011)]. MIMO techniques can be exploited both in downlink and uplink to improve transmission reliability and data rate, and it is possible to use up to a maximum of four transmit and four receive antennas [Iosif & Bănică (2013)].

Radio resources are allocated in a time/frequency domain. In the time domain, they are distributed every Transmission Time Interval (TTI), each one lasting 1 ms. Furthermore, each TTI is composed of two time slots of 0.5 ms, corresponding to 7 OFDM symbols in the default configuration with short cyclic prefix; 10 consecutive TTIs form the LTE Frame lasting 10 ms. In the frequency domain, instead, the whole bandwidth divides this into 180-kHz sub-channels, corresponding to 12 consecutive and equally spaced sub-carriers [Yaacoub (2012)]. A time/frequency radio resource, spanning over one timeslot lasting 0.5 ms in the time domain and over one sub-channel in the frequency domain, is called Resource Block (RB) and corresponds to the smallest radio resource that can be assigned to a UE for data transmission [Khan et al. (2012)]. Note that, given that the sub-channel dimension is fixed, the number of sub-channels varies according to different system bandwidth configurations (e.g., 25 and 50 RBs for system bandwidths of 5 and 10 MHz, respectively).

Scheduling in LTE System

At the eNB, the packet scheduler distributes radio resources among active users in order to satisfy their Quality of Service (QoS) needs. Scheduling decisions are strictly related to the channel quality experienced by UEs. In particular, the UE periodically measures this channel quality using reference symbols; then it sends the CQI feed back to the eNB, with an uplink control message [Dahlman et al. (2007)]. The information about the quality of the time and frequency variant channel is exploited by the link

adaptation module to select, for each UE, the most suitable Modulation and Coding Scheme (MSC) at the physical level with the objective of the spectral efficiency maximization. This approach is known as Adaptive Modulation and Coding (AMC) and it has been adopted by several wireless technologies, such as Enhanced Data for GSM Evolution (EDGE) [Halonen et al. (2003)] and Worldwide Interoperability for Microwave Access (WiMAX) [Andrews et al. (2007)].

Downlink control signaling is carried by three physical channels [Iosif & Bănică (2011)]; and the most important from a scheduling perspective is the Physical Downlink Control Channel (PDCCH), which carries assignments for downlink resources and uplink grants, including the used MCS as shown in Fig. 1. Considering that each modulation scheme corresponds to a fixed physical data rate, the link adaptation module establishes the maximum available physical data rate for each UE (based on the received channel quality information) to provide an optimal resource allocation among all users.

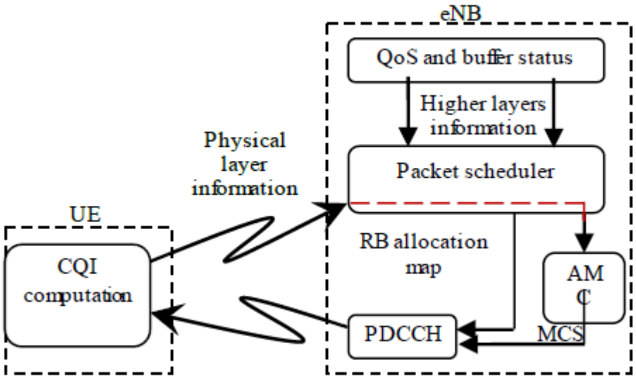

FIG. 1 SIMPLIFIED MODEL OF LTE PAKET SCHEDULER

Resource allocation for each UE is usually based on the comparison of per-RB metrics: the $k-th$ RBs allocated to the $j-th$ user if its metric $m_{j,k}$ is the biggest one, i.e., if it satisfies the equation [Capozzi et al. (2012)]:

$$m_{j,k} = \max_{i}\{m_{i,k}\} \tag{1}$$

For example, the best-CQI scheduling algorithm aims at maximizing the overall throughput by assigning each RB to the user that can achieve the maximum throughput in the current TTI. Its metric can be simply expressed as [Capozzi et al. (2012)]:

$$m_{i,k}^{best-CQI} = r_k^i(t) \tag{2}$$

where $r_k^i(t)$ is the instantaneous throughput for the $i-th$ user at time instant (TTI) t on the $k-th$ RB (calculated based on the CQI). In terms of fairness, this scheduling algorithm is not fair. In a practical situation, each mobile terminal will experience different channel conditions on each RB, due to differences in the distance and shadow fading between the base station and the mobile terminal. In this case, for a relatively long time, the channel conditions experienced by one mobile terminal could be worse than those experienced by other mobile terminals, and the best-CQI scheduling algorithm may 'starve' the mobile terminals with the bad channel condition in the way that the mobile terminal(s) with bad channel conditions will never be scheduled (i.e. example users at the cell edge). In a worst case scenario, (virtually all the time) only one user could be scheduled [Talevski & Gavrilovska (2012)].

A practical scheduler should be capable of maximizing the over all system capacity while still satisfying some degree of fairness among the users. The proposed scheduling algorithm tends to distribute the resources fairly among different users, therefore enabling fairness while at the same time trying to maximize system capacity performances within the cell.

The Enhanced PF Scheduling Scheme

The idea of PF scheme is that the past average throughput can act as a weighting factor of the expected data rate, so that users in bad conditions will be surely served within a certain amount of time. Its metric can be simply expressed as [Wu & Chu (2011), Nonchev & Valkama (2009)]:

$$m_{i,k}^{PF} = \frac{r_k^i(t)}{\bar{R}^i(t)}, \tag{3}$$

where $\bar{R}^i(t)$ is the average delivered throughput to the $i-th$ user until time t and can be updated using an exponentially weighted low-pass filter [Wang et al. (2003), Nonchev & Valkama (2009)]:

$$\bar{R}^i(t+1) = \left(1-\frac{1}{t_c}\right)\bar{R}^i(t) + \frac{1}{t_c}r_i(t). \tag{4}$$

Here t_c is the averaging window length over which the average delivered throughput is calculated and $r_i(t)$ denotes the actually realized throughput to the $i-th$ user at the previous TTI.

According to [Sun et al. (2006)], for conventional PF scheduling algorithm, the $k-th$ RB should be allocated to the $j-th$ UE such that:

$$j = \arg\max_{i}\left(\frac{r_k^i(t)}{(t_c-1)\bar{R}^i(t)+r_i(t)}\right). \tag{5}$$

The proposed enhanced scheduling algorithm aims to achieve a significant increase in the total throughput with a slight reduction in the fairness performance compared to the conventional PF scheduling algorithm.

The new metric of the proposed enhanced scheduling algorithm can be written as:

$$m_{i,k}^{Enh} = \log_2\left(r_k^i(t)\right) - \alpha\log_2\left((t_c - 1)\bar{R}^i(t) + r_i(t)\right). \quad (6)$$

So, according to the new metric the $k-th$ RB should be allocated to the $j-th$ UE such that:

$$j = \arg\max_i \log_2\left(r_k^i(t)\right) - \alpha\log_2\left((t_c - 1)\bar{R}^i(t) + r_i(t)\right). \quad (7)$$

The new parameter α introduced in the proposed metric equation is responsible for controlling the trade-off between throughput and fairness achieved by the proposed enhanced scheduling algorithm. The operating range of α is between 0 and 1 (0<α<1), when α =1 the proposed enhanced scheduling algorithm gives the same performance of the conventional PF scheduling algorithm which is characterized by high fairness but with low spectral efficiency. On the other hand, when α=0, the proposed enhanced scheduling algorithm gives the same performance of the best-CQI scheduling algorithm which is characterized by high throughput but with poor fairness performance.

As it can be seen later in the following simulation results section that the proper selection of the value of parameter α gives significant increase in the achieved throughput with slight reduction in fairness performance.

Performance Evaluation and Simulation Results

The performance evaluation of the scheduling algorithms is done by using the LTE Link Level Simulator (LLS) [Ikuno et al. (2010)]. The main simulation parameters used in this simulator are summarized in Table 1.

TABLE 1 THE SYSTEM SIMULATION PARAMETERS [Ikuno et al. (2010)].

Parameter	Value
Frequency Band	2.14 GHz
System Bandwidth	20 MHz
No. of User Equipments (UE) per eNB	20 UEs
No. of eNB	9 eNBs
Simulation Length	100 TTIs
Antenna Configuration	1 Transmit, 1 Receive (1X1)
UE Speed	5 km/hr
Uplink Delay	3 TTIs
The Distance between eNBs	500 m
eNB's Transmit Power	40 watts
The Thermal Noise Density	-174 dBm/Hz
Receiver Noise Figure	9 dB

Simulation results are presented to analyze and compare the performance of the proposed enhanced (referred to as Enh) with that of the best-CQI and the PF scheduling algorithms.

Fig. 2 and Fig. 3 present the throughput and fairness performance respectively of the proposed enhanced scheduling algorithm compared with that of the PF and the best-CQI scheduling algorithms.

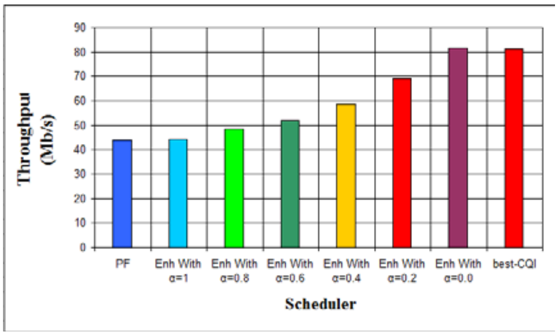

FIG. 2 AVERAGE CELL THROUGHPUT FOR DIFFERENT SCHEDULING ALGORITHMS

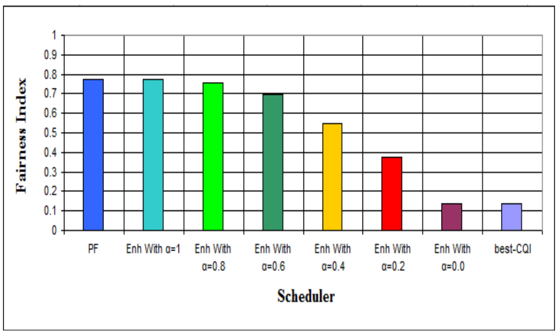

FIG. 3 FAIRNESS INDEX FOR DIFFERENT SCHEDULING ALGORITHMS

It is shown that the best-CQI is obviously able to maximize cell throughput, however, , it performs unfair resource sharing since users with poor channel conditions (e.g., cell-edge users) will only get a low percentage of the available resources (or in extreme case they may suffer of starvation). On the other hand, the proposed enhanced scheduling algorithm and the PF scheduling algorithm are able to guarantee high fairness level.

For the proposed enhanced scheduling algorithm as the value of α decreases (from 1 to 0), the average cell throughput significantly increases while the fairness level slightly decreases. For example, with α= 0.8, the proposed algorithm improves the average cell throughput by more than 10.3%, with approximately the same fairness level (2.6 % reduction) as compared with the conventional PF scheduling algorithm. Also, with α = 0.6, the proposed enhanced scheduling algorithm improves the average cell throughput by more than 18%, with 10% reduction of the fairness level as compared with the PF scheduling algorithm.

The Average Cell Throughput and Fairness Index for Different Scheduling Algorithms are summarized in Table 2.

TABLE 2 THE AVERAGE CELL THROUGHPUT AND FAIRNESS INDEX FOR DIFFERENT SCHEDULING ALGORITHMS.

Scheduling Algorithm	Throughput (Mb/s)	Fairness
PF	44.06	0.776179
Enh with α=1	44.17	0.776311
Enh with α=0.8	48.61	0.755492
Enh with α=0.6	52.02	0.659927
Enh with α=0.4	58.52	0.548118
Enh with α=0.2	69.1	0.372397
Enh with α=0.0	81.54	0.136801
best-CQI	81.37	0.138275

Conclusions

This paper elaborates the downlink packet scheduling framework in LTE by proposing a Capacity Enhancement based PF Scheduling algorithm, and its performance is compared with the best-CQI and PF algorithms. The modified PF algorithm allows fair distribution of available resources with the increasing spectral efficiency. Simulation results presented in the paper show that the implementation of this modified PF algorithm enables improvement of the overall system capacity and also provides fairness in the distribution of the resources.

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